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(54) Title: RHEOLOGY-MODIFIED THERMOPLASTIC ELASTOMER COMPOSITIONS AND ARTICLES FABRICATED THEREFROM (57) Abstract Rheology-modified TPE compositions are prepared by peroxide modification of a melt blend of an EAO polymer or EAO polymer blend and a high melting polymer such as polypropylene or a propylene/ α -olefin copolymer. The resulting compositions have an elastomeric phase, a non-elastomeric phase and certain physical properties that exceed those of a like composition that is not rheology-modified or of the same composition prior to rheology modification. The compositions can be used to make a variety of articles of manufacture, such as automotive parts, non-automotive parts, roofing membranes, and boot shafts, via conventional procedures.		

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RHEOLOGY-MODIFIED THERMOPLASTIC ELASTOMER COMPOSITIONS AND ARTICLES FABRICATED THEREFROM

5 FIELD OF THE INVENTION

This invention relates generally to rheology-modified thermoplastic elastomer (TPE) compositions that comprise an elastomeric ethylene/alpha (α)-olefin (EAO) polymer or EAO polymer blend and a high melting propylene polymer, preparation of the compositions, use of such compositions in processes such as profile extrusion and injection molding to make articles of manufacture and the resulting articles of manufacture. This invention particularly relates to such compositions wherein both components are peroxide-modified, methods for preparing the compositions, such as by use of a peroxide to modify a physical blend of the components, and use of such compositions to produce fabricated articles including thin-walled parts such as work boot shafts via injection molding, refrigerator gaskets via profile extrusion and automotive skins via sheet extrusion and/or calendering and then thermoforming.

BACKGROUND OF THE INVENTION

Manufacturers of elastomeric parts engage in an ongoing search for elastomers with processing characteristics that allow them to attain any or all of higher rates of productivity, improved quality and broader markets. Conventional processes used to make such parts include, without limitation, injection molding, profile extrusion, film extrusion, blown film, sheet extrusion processes. Four useful measures of how a formulation or composition will process are shear thinning index (STI), melt strength (MS), solidification temperature (ST) and upper service temperature (UST). Improvements in these properties have a direct affect upon productivity, quality and market breadth relative to such elastomeric parts.

STI, as used herein, is a ratio of polymer viscosity at a specified low shear rate divided by polymer viscosity at a specified high shear rate. For

EAO polymers, a conventional STI test temperature is 190° centigrade (°C).

Polymer viscosity is conveniently measured in poise (dyne-second/square centimeter (d-sec/cm²)) at shear rates within a range of 0.1-100 radian per second (rad/sec) and at 190°C under a nitrogen atmosphere using a dynamic mechanical

5 spectrometer such as a RMS-800 or ARES from Rheometrics.

MS, as used herein, is a maximum tensile force, in centiNewtons (cN), measured on a molten filament of a polymer melt extruded from a capillary rheometer die at a constant shear rate of 33 reciprocal seconds (sec⁻¹) while the filament is being stretched by a pair of nip rollers that are
10 accelerating the filament at a rate of 0.24 centimeters per second per second (cm/sec²) from an initial speed of 1 cm/sec. The molten filament is preferably generated by heating 10 grams (g) of a polymer that is packed into a barrel of an Instron capillary rheometer, equilibrating the polymer at 190°C for five minutes (min) and then extruding the polymer at a piston speed of 2.54 cm/min through a
15 capillary die with a diameter of 0.21 cm and a length of 4.19 cm. The tensile force is preferably measured with a Goettfert Rheotens that is located so that the nip rollers are 10 cm directly below a point at which the filament exits the capillary die.

ST, as used herein, is the temperature of the highest
20 temperature peak endotherm measured during cooling (in °C) with a differential scanning calorimeter (DSC), such as that sold by TA Instruments, Inc., as the polymer is first heated at a rate of 10°C/min from ambient temperature to a temperature of 200°C, then cooled at a rate of 10°C/min to a temperature of -30°C and then typically reheated at a rate of 10°C/min to a temperature of 200°C.

UST, as used herein, is that temperature (°C) at which a
25 thermomechanical analyzer (TMA) penetration probe penetrates a specimen having a thickness of two to three millimeters (mm) to a depth of 900 micrometers (µm). TA Instruments, Inc produce a suitable TMA. A one Newton (N) force is applied to the penetration probe as it rests on a surface of the specimen that is in a
30 chamber where temperature is ramped at a rate of 5°C/min.

When using a profile extrusion process, a manufacturer usually desires an elastomer that "shear thins" or decreases in viscosity with applied shear forces. Because pressure drop across an extruder die and amperage required to turn an extruder screw are directly related to elastomer viscosity, a reduction in elastomer viscosity due to shear thinning necessarily leads to a lower pressure drop and a lower amperage requirement. The manufacturer can then increase extruder screw speed until reaching a limit imposed by amperage or pressure drop. The increased screw speed translates to an increase in extruder output. An increase in shear thinning also delays onset of surface melt fracture (OSMF), a phenomenon that otherwise limits extruder output. Surface melt fracture (SMF) is usually considered a quality defect and manufacturers typically limit extruder output and suffer a productivity loss to reach a rate of production that substantially eliminates SMF.

When producing profile extrusions with thin walls and a complex geometry, a manufacturer looks for an elastomer with high MS and rapid solidification upon cooling in addition to good shear thinning behavior. A combination of a high MS and rapid solidification upon cooling (high ST) allows a part to be extruded hot and cooled below the elastomers ST before gravity and extrusion forces lead to shape distortion. Ultimately, for broad market acceptance, a finished part should also retain its shape despite short-term exposure to an elevated temperature during processing, shipping or eventual use.

The characteristics of high STI, high MS, rapid solidification (high ST) and increased UST are also important to manufacturers who produce elastomeric parts via injection molding. Resin pressure during injection is directly related to viscosity of the resin under specific shear conditions. Viscosity reductions due to shear thinning lowers resin pressure and reduce clamp tonnage requirements. A high MS helps eliminate part distortion during removal of a freshly molded part from a mold. In addition, rapid solidification and increased UST allow a second polymer to be injection molded over the part without that part being deformed or melted during the second injection. Rapid solidification leads to shorter cycle times. Finally, a part must retain its strength at service

temperatures and an increase in UST opens up additional markets for elastomeric parts.

Elastomeric part manufacturers who fabricate thin-walled (e.g. 2.5 mm thick), injection molded parts such as shafts (with a height of, for example, 18 inches (in) (45.7 cm) for industrial work boots have additional requirements beyond those specified for injection molding. They require a Shore A hardness of 30-60, preferably 35-50, for comfort around a wearer's calf. For articles of manufacture like work boots, they also seek a lower density material to make the resulting article lighter, good low temperature flexibility and improved resistance to chemicals, solvents or both. As an illustration, flexible polyvinylchloride (PVC) has a density of about 1.33 g per cubic centimeter (g/cc) and less than desirable cold temperature flexibility. Oil extended styrene block polymers such as styrene/butadiene/styrene (SBS) polymers have a density of about 1.05 g/cc and undesirable chemical resistance, solvent resistance or both.

Manufacturers who prepare elastomeric extruded and blown films and calendered sheets seek the same characteristics as those who use injection molding. An improved or increased shear thinning rheology leads to higher production rates before OSMF with its attendant variability in film or sheet thickness. A high MS promotes bubble stability in a blown film operation and provides a wide window of operations for further processing of such films via thermoforming. A high MS also promotes roll release during calendering. Rapid solidification or solidification at a higher temperature keeps an embossed calendering profile from collapsing or being wiped out. As with injection molding, an increase in UST leads to an expansion of potential markets for resulting film and sheets.

Linear EAO polymers produced via metallocene catalysis and substantially linear ethylene and EAO polymers (SLEPs) produced via constrained geometry catalysis have densities of 0.91 g/cc or less. These polymers provide additional options for fabricators of elastomeric parts. At least some of these polymers process like traditional thermoplastic polymers but have a degree of pliancy and flexibility typically associated with softer, rubberlike materials. With

technology advances, certain of these polymers now have a density (ρ) as low as 0.86 g/cc and a Shore A hardness, measured in accordance with American Society of Testing and Materials (ASTM) test D-2240, of 64. The latter polymers have excellent light and oxidation resistance, but their melting points may be as low as
5 43 °C due to their low levels of crystallinity.

The use of linear EAOs and SLEPs, particularly those with the lowest densities, has led to a desire for improvements in an overall balance of processing characteristics. The desire includes simultaneous advances in STI, MS, ST and UST. These advances are constrained by a requirement to
10 substantially avoid generation of gel particles. Gel particles, when present, adversely affect the appearance of thin-walled extrusions, films and sheets.

U. S. Patent Application serial number 60/012873, filed March 5, 1996, teaches rheological modification of EAO copolymers via use of peroxide. One benefit resulting from such use is an ability to increase the STI
15 from 7.6 for an unmodified resin up to 158.5 for a modified resin. Use of peroxide also yields an increase in MS at 150° C from 0.81 cN for unmodified resin to 66.75 cN for a modified resin. These benefits are achieved without a measurable gel content. Peroxide modification does not, however, result in any improvement in either UST or ST of an EAO copolymer.

20 W.K Fischer provides a variety of teachings regarding blends of an EAO polymer with a polyolefin. For example, US-A-3,758,643 and US-A-3,806,558 contain teachings about partially cured blends of an EAO copolymer with a polyolefin. US-A-3,862,106 relates to thermoplastic dynamically cured blend of EAO copolymers with a polyolefin. Both partial
25 curing and dynamic curing lead to an increase in insoluble gel content. Testing for insoluble gel content (or gel value) uses cyclohexane at 23°C. An acceptable substitute is boiling xylene, a common solvent that yields a gel value 30-50 % lower than that found using cyclohexane. Fischer provides several examples in which gel particles are present at a high enough level to cause unacceptable
30 roughness when partially cured or dynamically cured compositions are extruded as a 1/8 in rod.

G. Von Bodungen et al. teach, in US-A-3,957,919, incorporation of polyethylene (PE) into the thermodynamically cured EAO/polyolefin blend compositions of US-A-3,862,106. The PE helps protect polyolefins such as polypropylene (PP) from chain scission. This leads, in turn, to
5 an increased gel content as measured with cyclohexane.

A.Y. Coran et al. teach, in US-A-4,130,535, thermoplastic vulcanizates (TPVs) comprising blends of a crystalline thermoplastic polyolefin and a vulcanized EAO copolymer rubber. These compositions have a high gel content as no more than 3 % of the rubber is extractable in cyclohexane at 23°C.

10 SUMMARY OF THE INVENTION

It has now surprisingly been found that even though rheology modification, such as by addition of a peroxide, has no effect on the ST or UST limit of an EAO polymer, it has a dramatic effect on the ST and UST limits of blends of at least one elastomeric EAO polymer or EAO polymer blend and a
15 high melting polyolefin such as PP. In addition, rheology modification of such blends yields a STI that exceeds the STI of (a) a rheology modified EAO polymer or EAO polymer blend or (b) a blend, without rheology modification, of the same high melting polyolefin and an EAO polymer or EAO polymer blend.

One aspect of this invention is a rheology-modified,
20 substantially gel-free TPE composition comprising an EAO polymer or EAO polymer blend and at least one high melting polymer selected from PP homopolymers and propylene/ethylene (P/E) copolymers, the composition having at least three of four characteristics, the characteristics being a STI of at least (\geq)
25 $\geq 10^\circ\text{C}$ greater than that of the composition without rheology modification, and an UST limit $\geq 10^\circ\text{C}$ greater than that of the composition without rheology modification.

The rheology-modified TPE compositions may be compounded with conventional additives or process aids including, for example, fillers,
30 stabilizers, dispersants, pigments and process oils. Compounds prepared from the

rheology modified polymers of this invention retain their processing advantages over compounds prepared from the same polymers, but without rheology modification. The rheology modification is preferably induced via a peroxide, but may be accomplished thermally or by irradiation, including e-beam.

5 In a first related aspect, the TPE compositions of the first aspect may further comprise at least one additive selected from process oils, fillers and blowing agents.

 In a second related aspect, the TPE compositions of the first aspect may be blended with another polymer, preferably one of the polymers used
10 to make the TPE composition, prior to fabrication of an article of manufacture. Such blending may occur via any conventional technique. One technique includes dry blending pellets of the TPE composition with pellets of another polymer.

 A second aspect of this invention is a process for preparing a rheology-modified, substantially gel-free TPE composition, the process
15 comprising: a) providing a combination of an organic peroxide and a molten polymer composition that comprises at least one of (1) an elastomeric EAO polymer or EAO polymer blend and (2) a high melting polymer selected from PP homopolymers and P/E copolymers; and b) maintaining the combination in a melt state while subjecting it to conditions of shear sufficient to (1) disperse the
20 peroxide throughout the molten polymer composition, (2) effect sufficient rheology modification of the molten polymer composition and (3) substantially preclude formation of insoluble polymer gels, sufficient rheology modification being measured by a combination of at least three of four characteristics, the characteristics being a $STI \geq 20$, a $MS \geq 1.5$ times that of the polymer blend
25 without rheology modification, a $ST \geq 10^\circ C$ greater than that of the polymer blend without rheology modification, and an UST limit $\geq 10^\circ C$ greater than that of the polymer blend without rheology modification. The process optionally includes a step c) wherein the rheology-modified polymer blend is converted to an article of manufacture that has the combination of at least three of four
30 characteristics. The process may be further modified to comprise sequential intermediate steps b1) and b2) that precede step c). Step b1) comprises recovery

of the rheology modified polymer blend as a solid. Step b2) comprises conversion of the solid to a melt state sufficient for fabricating the article of manufacture.

One variation of the second aspect involves adding the high melting polymer to the molten polymer composition while the composition is in a melt state, but subsequent to rheology modification of the elastomeric EAO polymer or elastomeric EAO polymer blend.

A second variation of the second aspect involves adding, either before or after step b), at least one additive selected from process oils, fillers and blowing agents. The process oil, filler and blowing agent amounts are respectively within ranges of 0-50 weight percent (wt%), 0-70 wt%, and 0-10 wt%, all amounts being based on total composition weight. The filler, when present, is selected from glass, silica, carbon black, metal carbonates, metal sulfates, talc, clay and graphite fibers.

A third aspect of this invention is an article of manufacture having at least one component thereof fabricated from the TPE composition of the first aspect of the invention or prepared by the process of the second aspect of the invention. The compositions readily allow formation of articles of manufacture using apparatus with suitable upper pressure limitations combined with relatively long flow paths and narrow flow channels. The following paragraph contains a partial listing of suitable articles of manufacture.

DESCRIPTION OF PREFERRED EMBODIMENTS

The compositions of this invention can be formed into a variety of shaped articles using conventional polymer fabrication processes such as those identified above. A partial, far from exhaustive, listing of suitable shaped articles includes both automobile body parts and non-automotive parts. Automobile parts include bumper fascia, body side moldings, exterior trim, interior trim, air dams, air ducts, wheel covers and instrument and door panel skins. Non-automotive parts or applications include polymer films, polymer sheets, trash cans, storage containers, swim fins, lawn furniture strips or webbing, lawn mower and other garden appliance parts, recreational vehicle parts, golf cart parts, utility cart parts

and water craft parts. The compositions can also be used in roofing applications such as roofing membranes. The compositions can further be used in fabricating components of footwear such as a shaft for a boot, particularly an industrial work boot. A skilled artisan can readily augment this list without undue experimentation.

The rheology-modified compositions of this invention comprise an elastomeric EAO polymer or EAO polymer blend and a high melting polymer. The compositions desirably contain the EAO polymer or EAO polymer blend in an amount of 50-90 wt% and the high melting polymer(s) in an amount of 50-10 wt%, both percentages being based on composition weight. The amounts are preferably 65-85 wt% EAO and 35-15 wt% high melting polymer. The amounts are chosen to total 100 wt%.

EAO polymers (also referred to as "ethylene polymers") that are suitable for this invention include interpolymers and diene modified interpolymers. Illustrative polymers include ethylene/propylene (EP) copolymers, ethylene/butylene (EB) copolymers, ethylene/octene (EO) copolymers, ethylene/alpha-olefin/diene modified (EAODM) interpolymers and ethylene/propylene/diene modified (EPDM) interpolymers. More specific examples include ultra low linear density polyethylene (ULDPE) (e.g., Attane™ made by The Dow Chemical Company), homogeneously branched, linear EAO copolymers (e.g. Tafmer™ by Mitsui PetroChemicals Company Limited and Exact™ by Exxon Chemical Company), and homogeneously branched, substantially linear EAO polymers (e.g. the Affinity™ polymers available from The Dow Chemical Company and Engage® polymers available from DuPont Dow Elastomers L.L.C. Preferred EAO polymers include homogeneously branched linear and substantially linear ethylene copolymers with a density (measured in accordance with ASTM D-792) of 0.85-0.92 g/cc, especially 0.85-0.90 g/cc and a melt index or I₂ (measured in accordance with ASTM D-1238 (190°C/2.16 kg weight) of 0.01-30, preferably 0.05-10 g/10 min.

The substantially linear ethylene copolymers or interpolymers (also known as "SLEPs") are especially preferred. In addition, the various

functionalized ethylene copolymers such as EVA (containing from 0.5-50 wt % units derived from vinyl acetate) are also suitable. When using an EVA polymer, those that have an I_2 of from 0.01-500, preferably 0.05-50 g/10 min are preferred.

"Substantially linear" means that a polymer has a backbone
5 substituted with from 0.01-3 long-chain branches per 1000 carbons in the backbone.

"Long-chain branching" or "LCB" means a chain length that exceeds that of a short chain that results from incorporation of an α -olefin into the backbone of an EAO polymer or an EAO polymer blend. Although carbon-13
10 nuclear magnetic resonance (C^{13} NMR) spectroscopy cannot distinguish or determine an actual number of carbon atoms in the chain if the length is greater than six carbon atoms (C_6), the presence of LCB can be determined, or at least estimated, from molecular weight distribution (MWD) of the EAO polymer(s). It can also be determined from a melt flow ratio (MFR) or ratio (I_{10}/I_2) of melt index
15 (I_{10}), determined via ASTM D-1238 (190°C, 10 kg weight), to I_2 .

"Interpolymer" refers to a polymer having polymerized therein \geq two monomers. It includes, for example, copolymers, terpolymers and tetrapolymers. It particularly includes a polymer prepared by polymerizing
20 ethylene with at least one comonomer, typically a C_3 - C_{20} α -olefin, and desirably a C_3 - C_{10} α -olefin. Illustrative α -olefins are propylene, 1-butene, 1-hexene, 4-methyl-1-pentene, 1-heptene, 1-octene and styrene. Preferred copolymers include EP, EB, ethylene/hexene-1 (EH) and EO polymers. Illustrative terpolymers are an ethylene/propylene/octene terpolymer and terpolymers of ethylene, a C_3 - C_{20} α -
25 olefin and a diene such as dicyclopentadiene, 1,4-hexadiene, piperylene or 5-ethylidene-2-norbornene (ENB).

"Elastomeric" means an EAO polymer or EAO polymer blend with a density less than ($<$) 0.910 g/cc, desirably $<$ 0.900 g/cc, preferably $<$ 0.895 g/cc, more preferably $<$ 0.880 g/cc, still more preferably $<$ 0.875 g/cc, even more
30 preferably $<$ 0.870 g/cc and a percent crystallinity $<$ 33%, preferably $<$ 29% and

more preferably < 23%. The density is preferably greater than (>) 0.85 g/cc.

Percent crystallinity is determined by differential scanning calorimetry (DSC)

SLEPs are characterized by narrow MWD and narrow short chain branching distribution (SCBD) and may be prepared as described in United States Patent (US-A-) 5,272,236 and 5,278,272, relevant portions of both being
5 incorporated herein by reference. The SLEPs exhibit outstanding physical properties by virtue of their narrow MWD and narrow SCBD coupled with long chain branching (LCB).

US-A-5,272,236 (column 5, line 67 through column 6, line 28)
10 describes SLEP production via a continuous controlled polymerization process using at least one reactor, but allows for multiple reactors, at a polymerization temperature and pressure sufficient to produce a SLEP having desired properties. The process is preferably a solution polymerization process operating at a temperature of 20-250°C and using constrained geometry catalyst (CGC)
15 technology. Suitable CGCs are disclosed at column 6, line 29 through column 13, line 50 of USP 5,272,236.

A preferred SLEP has a number of distinct characteristics, such as an ethylene content of 20-90 wt%, more preferably 30-89 wt%, with the balance comprising one or more comonomers. The ethylene and comonomer
20 contents are based on SLEP weight and selected to attain a total monomer content of 100 wt%.

Additional distinct SLEP characteristics include I_2 and MFR or I_{10}/I_2 . The interpolymers desirably have an I_2 of 0.01-30 g/10 min, more preferably from 0.05-10 g/10 min. The SLEP also has a $I_{10}/I_2 \geq 5.63$, preferably 6.5-15, more
25 preferably 7-10. For a SLEP, the I_{10}/I_2 ratio serves as an indication of the degree of LCB such that a larger I_{10}/I_2 ratio equates to a higher degree of LCB in the polymer.

SLEPs that meet the aforementioned criteria include, for example, ENGAGE® polyolefin elastomers and other polymers produced using a
30 CGC by The Dow Chemical Company and DuPont Dow Elastomers L.L.C.

The high melting polymer is a homopolymer of propylene, a copolymer of propylene with an α -olefin such as ethylene, 1-butene, 1-hexene or 4-methyl-1-pentene. The polymer may also be a blend of a homopolymer and a copolymer, a nucleated homopolymer or a nucleated copolymer. It may further be
5 a nucleated blend of a homopolymer and a copolymer. The α -olefin is preferably ethylene. The copolymer may be a random copolymer or a block copolymer or a blend of a random copolymer and a block copolymer. This component is preferably selected from PP homopolymers and P/E copolymers with a melt flow rate (MFR) (230°C and 2.16 kg weight) of 0.3-60 g/10 min, preferably 0.8-40 g/10
10 min and more preferably 1-35 g/10 min.

As used herein, "nucleated" refers to a polymer that has been modified by addition of a nucleating agent such as Millad™, a dibenzyl sorbitol commercially available from Milliken. Other conventional nucleating agents may also be used.

15 Preparation of PP also involves the use of Ziegler catalysts such as a titanium trichloride in combination with aluminum diethylmonochloride, as described by Cecchin, US-A-4,177,160. Polymerization processes used to produce PP include the slurry process, run at 50-90°C and 0.5-1.5 MPa (5-15 atm), and both the gas-phase and liquid-monomer processes in which extra care
20 must be given to removal of amorphous polymer. Ethylene may be added to the reaction to form a polypropylene with ethylene blocks. PP resins may also be prepared by using any of a variety of metallocene, single site and constrained geometry catalysts together with their associated processes.

Suitable organic peroxides have a half-life \geq one hour at 120°
25 C. Illustrative peroxides include a series of vulcanizing and polymerization agents that contain α , α' -bis(t-butylperoxy)-diisopropylbenzene and are available from Hercules, Inc. under the trade designation VULCUP™, a series of such agents that contain dicumyl peroxide and are available from Hercules, Inc. under the trade designation Di-cup™ as well as Lupersol™ peroxides made by Elf Atochem,
30 North America or Trigonox™ organic peroxides made by Moury Chemical Company. The Lupersol™ peroxides include Lupersol™ 101 (2,5-dimethyl-2,5-

di(t-butylperoxy)hexane), Lupersol™ 130 (2,5-dimethyl-2,5-di(t-butylperoxy)hexyne-3) and Lupersol™ 575 (t-amyl peroxy-2-ethylhexonate). Other suitable peroxides include 2,5-dimethyl-2,5-di-(t-butyl peroxy)hexane, di-t-butylperoxide, 2,5-di(t-amyl peroxy)-2,5-dimethylhexane, 2,5-di-(t-butylperoxy)-
5 2,5-diphenylhexane, bis(alpha-methylbenzyl)peroxide, benzoyl peroxide, t-butyl perbenzoate and bis(t-butylperoxy)-diisopropylbenzene.

The peroxide is used in an amount sufficient to provide \geq three of four characteristics: a STI \geq 20, preferably \geq 25, more preferably \geq 30 and still more preferably \geq 35, a MS \geq 1.5 times, preferably \geq 1.6 times and more
10 preferably \geq two times that of the composition without rheology modification, a ST that is \geq 10° C greater than that of the composition without rheology modification, and an UST limit \geq 10° C greater than that of the composition without rheology modification. The peroxide is suitably present in an amount that is within a range of from 1500-10,000 parts by weight per million parts by weight
15 of polymer (ppm). The range is desirably 2,000-8,000, preferably 3,000-6,000 ppm.

The peroxide can be added by any conventional means known to skilled artisans. If a process oil is used in preparing the rheology-modified compositions, the peroxide may be injected during processing, as a solution or
20 dispersion in the process oil or another dispersing aid, into a processing apparatus at a point where the polymer blend is in a melt state. Concentration of the peroxide in the solution or dispersion may vary, but a 20-40 wt% concentration, based on solution or dispersion weight, provides acceptable results. The solution or dispersion can also be admixed with, and allowed to imbibe on, dry blended
25 polymer pellets. If the peroxide is a liquid, it may be used as is without forming a solution or dispersion in a process oil. One can, for example, add a liquid peroxide to a high speed blender together with dry polymer pellets, subject the blender contents to mixing action for a short period of time and then allow the contents to rest until imbibing action is regarded as sufficiently complete. On a
30 small scale, a Welex Papenmeier Type TGAHK20 blender (Papenmeier Corporation) can be used to provide mixing action for a time period such as 30-45

seconds. This is typically followed by a rest period of 30 minutes. In a more preferred procedure, a solid peroxide is added with the polymer pellets as the pellets enter a compounding apparatus. The peroxide can also be added to a polymer melt in a compounding apparatus such as a Haake, a Banbury mixer, a Farrel continuous mixer or a Buss kneader. The peroxide can also be added as a solid in conjunction with dry blending of the polymer pellets.

In order to detect the presence of, and where desirable, quantify insoluble gels in a polymer composition, simply soak the composition in a suitable solvent such as refluxing xylene for 12 hours as described in ASTM D 2765-90, method B. Any insoluble portion of the composition is then isolated, dried and weighed, making suitable corrections based upon knowledge of the composition. For example, the weight of non-polymeric, solvent-soluble components is subtracted from the initial weight and the weight of non-polymeric, solvent-insoluble components is subtracted from both the initial and final weight. The insoluble polymer recovered is reported as percent gel (% gel) content. For purposes of this invention, "substantially gel-free" means a % gel content that is desirably < 10%, more desirably < 8%, preferably < 5%, more preferably < 3%, still more preferably < 2%, even more preferably < 0.5% and most preferably below detectable limits when using xylene as the solvent. For certain end use applications where gels can be tolerated, the % gel content can be higher.

The compositions of this invention may be compounded with any one or more materials conventionally added to polymers. These materials include, for example, EAOs that have not been rheology modified, process oils, plasticizers, specialty additives including stabilizers, fillers (both reinforcing and non-reinforcing) and pigments. These materials may be compounded with compositions of this invention either before or after such compositions are rheology modified. Skilled artisans can readily select any suitable combination of additives and additive amounts as well as timing of compounding without undue experimentation.

If the rheology-modified EAO polymer blend is further modified or admixed with an EAO that has not been rheology-modified, such as

an EO copolymer with a Mooney viscosity (ML_{1+4} , 125°C) ≥ 50 , preferably ≥ 60 and more preferably ≥ 70 , the unmodified EAO is desirably present in an amount that falls within a range of from > 0 to 30 wt%, based on total composition weight. The range is preferably 5-20 wt%, more preferably from 8-20 wt%.

5 Process oils are often used to reduce any one or more of viscosity, hardness, modulus and cost of a composition. The most common process oils have particular ASTM designations depending upon whether they are classified as paraffinic, naphthenic or aromatic oils. An artisan skilled in the processing of elastomers in general and the rheology-modified TPE compositions
10 of this invention in particular will recognize which type of oil will be most beneficial. The process oils, when used, are desirably present in an amount within a range of 15-50 wt%, based on total composition weight.

A variety of specialty additives may be used in compositions of this invention. The additives include antioxidants; surface tension modifiers; anti-
15 block agents; lubricants; antimicrobial agents such as organometallics, isothiazolones, organosulfurs and mercaptans; antioxidants such as phenolics, secondary amines, phosphites and thioesters; antistatic agents such as quaternary ammonium compounds, amines, and ethoxylated, propoxylated or glycerol compounds; fillers and reinforcing agents such as carbon black, glass, metal
20 carbonates such as calcium carbonate, metal sulfates such as calcium sulfate, talc, clay or graphite fibers; hydrolytic stabilizers; lubricants such as fatty acids, fatty alcohols, esters, fatty amides, metallic stearates, paraffinic and microcrystalline waxes, silicones and orthophosphoric acid esters; mold release agents such as
25 esters such as trimethylolpropane tristearate or pentaerythritol tetrastearate; pigments, dyes and colorants; plasticizers such as esters of dibasic acids (or their anhydrides) with monohydric alcohols such as o-phthalates, adipates and benzoates; heat stabilizers such as organotin mercaptides, an octyl ester of thioglycolic acid and a barium or cadmium carboxylate; ultraviolet light
30 stabilizers such as a hindered amine, an o-hydroxy-phenylbenzotriazole, a 2-hydroxy,4-alkoxybenzophenone, a salicylate, a cyanoacrylate, a nickel chelate and a

benzylidene malonate and oxalanilide; and zeolites, molecular sieves and other known deodorizers. A preferred hindered phenolic antioxidant is IrganoxTM 1076 antioxidant, available from Ciba-Geigy Corp. Each additives, if used, is typically present in an amount of < 45 wt%, based on total composition weight. The
5 amount is advantageously 0.001-20 wt%, preferably 0.01-15 wt% and more preferably 0.1-10 wt%.

The rheology-modified TPE compositions may be fabricated into parts, sheets or other form using any one of a number of conventional procedures for processing TPEs. The compositions can also be formed, spun or
10 drawn into films, fibers, multi-layer laminates or extruded sheets, or can be compounded with one or more organic or inorganic substances, on any machine suitable for such purposes.

The rheology-modified TPE compositions have surprisingly improved properties relative to simple blends of an EAO copolymer and a high
15 melting polymer such as PP that have not been subjected to rheology modification. Rheology modification, whether it be by way of an organic peroxide or other free radical generating compound, use of a source of radiation, such as ultraviolet light or e-beam, or application of heat, with or without a compound such as an organic peroxide, provides a combination of \geq three of four
20 desirable and improved properties. Two of the properties of interest are an STI of ≥ 20 , preferably ≥ 25 , more preferably ≥ 30 and still more preferably ≥ 35 , and an UST limit, as measured by Rheometrics Dynamic Analysis (RDA), $\geq 10^\circ \text{C}$ greater than that of the composition without rheology modification. In an uncompounded state, two additional properties of interest for compositions of the
25 present invention are a MS that is ≥ 1.5 , preferably ≥ 1.6 and more preferably ≥ 2 times that of a like composition save for the absence of the rheology modification, and a ST that is $\geq 10^\circ \text{C}$ greater than that of the composition without rheology modification.

The following examples illustrate but do not, either explicitly
30 or by implication, limit the present invention. Unless otherwise stated, all parts (pbw) and percentages (wt%) are by weight, on a total weight basis. Examples

(Ex) of the present invention are identified by Arabic numerals and letters of the alphabet identifies comparative examples (Comp Ex).

EX 1-3 AND COMP EX A-F

Nine sample compositions, Ex 1-3 and Comp Ex A-F, are prepared from three different EAO polymers using a basic procedure for Ex 1-3 and certain modifications of the basic procedure for Comp Ex A-F. Feeding dry polymer pellets to a ZSK 30 millimeter (mm), Werner Pfleiderer, co-rotating, twin screw extruder equipped with high shear mixing screw sections processes all samples. The extruder operates at a speed of 250 revolutions per minute (rpm) to effectively melt process the dry pellets.

For Ex 1-3 and Comp Ex D-F, the pellets are a dry blend of 75 wt% EAO polymer and 25 wt% PP-1, a PP homopolymer (Profax® 6231, MFR (230°C and 2.16 kg weight) of 20 g/10 min, commercially available from Himont), both percentages being based on dry blend weight.

The EAO polymers, all available from DuPont Dow Elastomers L.L.C., are: EAO-1, a polyolefin elastomer (POE) (Engage® 8150) having a melt index (I_2) of 0.5 g/10 min (190°C, 2.12 kilograms (kg)) and a density (ρ) of 0.868 g/cc; EAO-2, a POE (Engage® 8180) having an I_2 of 0.5 g/10 min and a ρ of 0.863 g/cc; and EAO-3, a POE (Engage® 8842) having an I_2 of 1 g/10 min and a ρ of 0.858 g/cc.

A 20 wt% solution of peroxide (2,5-dimethyl-2,5-di(t-butylperoxy)hexane, available as Lupersol® 101 from Elf Atochem, North America) in O-3, a petroleum distillate, solvent-refined heavy paraffinic oil (Tuflo® 10, Lyondell) having a viscosity of 100 Saybolt Universal Seconds (SUS) at 100° Fahrenheit (°F) (38°C) is injected into the extruder at the beginning of zone 2 (of five zones). The solution is injected at a flow rate sufficient to provide a peroxide concentration of 3000 ppm, based on weight of polymer plus peroxide. Zones 1 and 2 are set, respectively, at 170 and 180°C. Zones 3-5 and the extruder die are set at 200°C. These temperatures provide a peak melt temperature of no more than 230°C.

Table I summarizes data for the nine samples. Table I lists the EAO polymer, specifies the wt% PP-1, and includes the amount of peroxide in ppm, STI, MS in cN, UST in °C, and ST in °C. Although not shown in Table I, the EAO polymers used in Table I typically have the following properties: an STI of 3-10, an MS of 3-7 cN, an UST of 57-70°C and a ST of 30-45°C.

Table I

Ex/ Comp Ex	EAO	PP-1 (wt%)	Perox- ide (ppm)	STI	MS (cN)	UST (°C)	ST (°C)
1	1	25	3000	61.2	7.3	92	112
2	2	25	3000	76.2	8.9	85	109
3	3	25	3000	44.5	9.5	54	96
A	1	25	0	5.5	4.8	72	79
B	2	25	0	11.3	5.4	70	78
C	3	25	0	3.0	3.6	61	85
D	1	0	3000	38.1	24.8	71	45
E	2	0	3000	33.1	28.3	62	39
F	3	0	3000	26.3	19.3	57	29

The UST value of 54°C for Ex 3 is believed to be in error. This belief stems from the data trends for other Ex of this invention.

10 The data presented in Table I illustrate several points. First, other than the anomalous data point for UST in Ex 3, the peroxide modified combination of an EAO and a PP (Ex 1-3) provides a desirable balance of STI, MS, UST and ST relative to the same combination without peroxide modification (Comp Ex A-C) and a peroxide-modified EAO (Comp Ex D-F). Second, a
15 peroxide modified EAO (Comp Ex D-F) has better STI and MS values, but lower ST values, than an EAO/PP blend lacking peroxide modification (Comp Ex A-C). Third, neither a peroxide-modified EAO nor an unmodified blend has an UST that

is as good as that of the peroxide modified blend (Ex 3 excepted). The UST and ST values of Ex 1-3 are particularly unexpected in light of the failure of rheology modification (by way of peroxide addition) of an EAO (Comp Ex D-F) to provide like UST and ST values.

5 Ex 4-7

Using EAO-1 and PP-2, the procedure and apparatus of Ex 1-3 are used to prepare four additional samples with the same peroxide at levels of 1500 and 4500 ppm rather than 3000 ppm, and PP levels of 15 and 35 wt% rather than 25 wt%. PP-2 (Profax™6523, Himont) has a MFR of 4 g/10 min. Table II
10 summarizes data for Ex 4-7.

Table II - Range of Applicability

Ex	PP-2 (wt%)	Perox-ide (ppm)	STI	MS (cN)	UST (°C)	ST (°C)
4	35	4500	85	3.7	146	111
5	35	1500	23	4.0	132	112
6	15	4500	80	20.0	67	97
7	15	1500	34	9.5	64	115

The data indicate that there is considerable latitude in tailoring
15 desired properties simply by varying the PP and peroxide contents of EAO/PP blends.

Ex 8 and 9

Using EAO-4 (Engage® 8190, a blend of 93 wt% of EAO-3
20 and 7 wt% PP-4 (Profax™ 6323, a PP homopolymer having a MFR of 12 g/10 min, available from Himont), the blend having an overall density of 0.859 g/cc and an I₂ of one g/10 min and being available from DuPont Dow Elastomers L.L.C.) and PP-4, the procedure and apparatus of Ex 1-3 are used to prepare two additional samples with the same peroxide at levels of 6000 and 10000 ppm rather

than 3000 ppm. Due to equipment limitations, the concentration of peroxide in the peroxide/oil is increased, respectively, to 25 and 33 wt%. A pump addition rate of 2.4 wt% of solution, based on weight of solution plus polymer, provides the 6000 ppm level and a rate of 3 wt% provides the 10,000 ppm level. Ex 8 and 9 have respective STIs of 56 and 100. The USTs of Ex 8 and 9 are, respectively, 150°C and 157°C. The MS of Ex 9 is 11 cN.

When the polymer output from the extruder is extruded through a 0.040 inch (1 mm) thick ribbon die at 330° F (166° C), Ex 8 and 9 both yield a smooth ribbon with no visible gels. When tested in refluxing xylene for 12 hours according to ASTM D-2765-90, method B, the respective insoluble gel contents for Ex 8 and 9 are 0.1% and 1.45 wt%.

The data in these examples demonstrate that satisfactory results, in terms of insoluble gel content, are obtained at higher peroxide contents than used for Ex 1-7. Ex 8 and 9 also have satisfactory UST and MS, as shown above, and are expected to have satisfactory STI and ST values. As the insoluble gel content should increase with increasing peroxide levels, Ex 1-7, all of which have lower peroxide levels, should also have lower gel contents.

Ex 10-12 and Comp Ex G-I

Using the procedure and apparatus of Ex 1-3 and Comp Ex A-C, six additional sample materials are prepared. Ex 10-12 all use a peroxide rheology modifier and Comp Ex G-I do not.

Ex 10 and Comp Ex G are prepared from 75 wt% of EAO-5 (an experimental EPDM polymer having a Mooney viscosity of 45, an ethylene content of 75 wt% and a diene content of no more than 8 wt% and being available from DuPont Dow Elastomers L.L.C.) and 25 wt% of PP-1, both percentages being based on combined polymer weight. Ex 10 uses a peroxide level of 3000 ppm.

Ex 11 and Comp Ex H are prepared from a blend of 80 wt% of EAO-6, a linear EP polymer (Tafmer™ P0180, Mitsui Petrochemical) having an I₂

of 8 and a density of 0.87 g/cc, and 20 wt% of PP-2, both percentages being based upon combined polymer weight. Ex 11 uses a peroxide level of 6000 ppm.

Ex 12 and Comp Ex I are prepared from a blend of 80 wt% of EAO-7, a linear ethylene polymer (Exact® 4003, Exxon Chemical) and 20 wt% of PP-2, both percentages being based on combined polymer weight. Ex 12 uses a peroxide level of 6000 ppm.

Data for Ex 10-12 and Comp Ex G-I are summarized in Table III.

Table III - Range of Applicability

Ex/ Comp Ex	PP (wt%)	Perox-ide (ppm)	STI	MS (cN)	UST (°C)	ST (°C)
10	25	3000	174	26	159	111
G	25	0	30	12	64	52
11	20	6000	44	11.6	56	120
H	20	0	2.8	<0.5	53	83
12	20	6000	65	8.7	88	120
I	20	0	2.2	<0.5	87	70

The data presented in Table III show that other EAO polymers and PP polymers yield satisfactory results in terms of at least three of MS, STI, UST and ST when the rheology-modified compounds are compared with their respective unmodified counterparts.

Comp Ex J and K

Two rheology-modified compositions are prepared using a different propylene polymer, a different procedure and a different apparatus than those used for Ex 1-3 and Comp Ex A-F. As an initial step, weigh feeders proportionally feed 75 pbw of EAO-1 and 25 pbw of PP-3, a P/E copolymer (Rexene® 23S2A, MFR of 2 g/10 min, commercially available from Rexene

Products Company) onto a vibratory belt. The vibratory belt dry blends the polymers as it feeds them to an extruder's throat.

The extruder is a Berlyn 2.5 inch (6.35 cm), 32:1 single screw extruder with a 75 horsepower (HP) motor. The extruder screw is a Newcastle Industries rheology modification screw (32.5 inch (82.55 cm) transition zone, 7.25 inch (18.42 cm) gear mixing zone, 13.5 inch (34.29 cm) vented metering zone, and 30.5 inch (77.47 cm) transition zone following an initial feed zone). The zones are heated to temperatures as follows: zone 1, 225°C; zone 2, 225°C; zone 3, 125°C; zone 4, 200°C; and zone 5, 200°C. The screw turns at a rate of 120 rpm to provide a polymer output of 150 pounds (68.0 kilograms (kg)) per hour. The polymer output is pelletized using a GALA underwater pelletizer and a 12 hole die (3 mm/hole) with a two blade cutter head rotating at 1383 rpm.

A peroxide solution comprising 20% di(tertiary butyl peroxide) and 80% mineral oil (Drakeol® 34, 0.865 specific gravity, available from Penreco) is injected through a port in the extruder barrel at a point just past where a gear mixer starts. The solution is injected at a pressure of 2500 pounds per square inch (psi) (17.2 megapascals (MPa)) using a Williams V-Series pneumatic metering pump. The injection rates are adjusted to provide respective peroxide levels for Comp Ex J and K of 4000 ppm and 6000 ppm.

When the polymer output from the extruder is extruded through the ribbon die as in Ex 8 and 9, Comp Ex J and K both yield a product with a rough surface appearance and clearly visible gels. The respective insoluble gel contents for Comp Ex J and K are 22.4% and 26.6%.

When the compositions of Comp Ex J and K are processed using the twin screw apparatus of Ex 1-3 and lower initial zone temperatures, the enhanced mixing provided by that apparatus yields quite satisfactory results. When processed through the ribbon die, the compositions produce a smooth surface appearance and no visible gels. When subjected to the refluxing xylene test, there are no extractable insoluble gels.

The contrasting results obtained with the same composition on different apparatus highlight the importance of adequate dispersion of a rheology-

modifier throughout a molten polymer composition before localized gels are created. Similar undesirable results, in terms of excessive insoluble gel content, are expected if temperatures within the extruder are too high or if a dispersing aid, such as the process oil, is omitted when adding a rheology modifier. Skilled
5 artisans recognize that a dispersing aid may, however, be eliminated when rheology modification occurs via radiation rather than by use of an additive such as an organic peroxide.

Ex 13-16

Ex 13 is prepared using gravimetric feeders to feed 75 wt%
10 EAO-8 pellets (Engage® 8100, an EO copolymer with a ρ of 0.87 g/cc and an I_2 of 1 g/10 min (DuPont Dow Elastomers L.L.C.)) and 25 wt% PP-4 pellets (Profax® 6323, polypropylene homopolymer with a MFR of 12 g/10 min, available from Himont) to a ZSK 30 mm twin screw extruder as in Ex 1-3. A 33
15 wt% solution of the same peroxide as in Ex 1-3 in O-2, a naphthenic oil (viscosity of 200 SUS at 100°F (38°C) (Shellflex® 3271, Shell Chemical)) is injected into the extruder at a point where a polymer melt begins to enter an intensive gear mixing section. The injection rate is proportioned to the polymer output such that the peroxide is present at a concentration of 7000 ppm. The extruder has six
20 zones, all but two of them being set at 200° C. The other two are a feed zone set at 160° C and an injection zone set at 170° C. Due to heat generated by shear mixing, the polymer melt reaches a temperature that does not exceed 220° C. Based upon a residence time within the extruder that exceeds six half lives for the peroxide, substantially all of the peroxide is believed to be consumed within the extruder.

25 Ex 14 is prepared using the same polymer blend and peroxide solution as in Ex 13, but with a variation of the process used to prepare Ex 13. Instead of injecting the peroxide solution into the extruder, the peroxide solution is poured over the blended EAO and PP pellets and immediately placed in a tumbler mixer. Mixing continues for 30 minutes to allow the pellets to absorb the
30 peroxide solution. The tumbler contents are then fed to the same extruder used to

prepare Ex 13. This process variation simulates compounding in the absence of an injection pump capable of injecting peroxide to the extruder.

Ex 15 is prepared by another variation of the process of Ex 13.

A solid peroxide, α, α' -bis(t-butylperoxy)-diisopropylbenzene (Vulcup™ R, Hercules, Inc.), is used in place of the peroxide solution. The peroxide, normally a waxy crystalline solid, is made into a powder with a spatula and then added in an amount of 7000 ppm to a fiber drum containing 75 wt% EAO-8 pellets and 25 wt% PP-4 pellets. The fiber drum is tumbled for 30 minutes to dry mix the contents before feeding them to the extruder. This variation eliminates the need for liquid handling equipment.

Ex 16 duplicates Ex 13 save for changing the EAO to EAO-9 and increasing the peroxide amount to 8000 ppm. EAO-9 is an EO copolymer (Engage® 8003, available from DuPont Dow Elastomers L.L.C.) with a ρ of 0.885 and an I_2 of 1 g/10 min.

Table IV summarizes the results obtained by evaluating the rheology-modified blends of Ex 13-16 in terms of STI and UST. The variations in STI are believed to stem from a number of factors. First, the effect of peroxide modification on an EAO/PP blend tends to increase with increasing EAO density. See, Ex 16 (EAO-9 density of 0.885 g/cc) and Ex 13 (EAO-8 density of 0.87 g/cc). Second, certain peroxides are more effective than others in building STI. Compare Ex 15 (VULCUP™ R) with Ex 13 (Lupersol® 101). Third, an increase in the amount of peroxide, as in Ex 16 versus Ex 13, also increases STI.

Table IV

Ex No	STI	UST (°C)
13	97	150
14	111	149
15	196	159
16	168	156

Ex 17

Using the procedure of Ex 15, a sample is prepared from 75 wt% EAO-10 pellets, 25 wt% PP-4 pellets and 5000 ppm of the peroxide used in Ex 15. EAO-10 is an experimental EO copolymer prepared by DuPont Dow Elastomers L.L.C. and having a Mooney viscosity (ML_{1+4} , 125°C) of 70 and a ρ of 0.87 g/cc. The resulting rheology-modified blend has a UST of 166°C and an STI of 250.

Ex 18

Using gravimetric feeders, 80 wt% EAO-2 pellets and 20 wt% PP-4 pellets are fed to a Berstorff 40 mm twin screw extruder. A 25 wt% solution of the same peroxide as in Ex 1-3 in the same process oil as used in Comp Ex J-K is injected into the extruder as in Ex 13. The extruder has nine zones, all but two of them being set at 200° C. The others are a feed zone set at 170° C and an injection zone set at 180° C. Due to heat generated by shear mixing, the polymer melt reaches a temperature that does not exceed 235° C. Based upon a residence time within the extruder that exceeds six half lives for the peroxide, substantially all of the peroxide is believed to be consumed within the extruder. This material is used as an intermediate for further compounding.

A compound is prepared using 70 pbw of the intermediate, 20 pbw of the same process oil as used in preparing the intermediate and 10 pbw of stearate coated calcium carbonate (CaCO_3) (Kotamite™, ECC International). The compound is processed through a three inch (7.6 cm) single screw extruder equipped with a refrigerator gasket die. The resulting gasket profile has three closed sections that are inflated with air and a wall thickness that varies from 0.017 inch (0.43 cm) to 0.60 inch (1.5 cm). The compound extrudes in a problem-free manner at a rate of 67 feet (20.4 meters (m)) per minute. The extrudate has a MS that is sufficient to enable the profile to retain its shape until water spray cooling can reduce the profile to a temperature below the ST of the intermediate. The resulting gasket has a modulus that is low enough to allow it to be easily extended and compressed.

Comp Ex L

A compound is prepared from 57 wt% EAO-1, 17 wt% PP-3, 18 wt% of the process oil of Ex 18 and 10 wt% of the same CaCO_3 as used in Ex 18, all percentages being based on compound weight. The compound, when
5 processed in the same manner as detailed in Ex 18, extrudes poorly. While there is no evidence of SMF, the MS is too low to prevent the gasket profile from collapsing. In addition, spraying water on the profile to cool it leads to rapid shrinkage and discernible part distortion. The resulting gasket is too stiff to extend and compress in the same manner as the gasket of Example 18.

10 Ex 19-25 and Comp Ex M-O

Rheology-modified and oil-extended compounds are prepared using the following procedure (with one modification for Comp Ex M-N). For Comp Ex M-O, no peroxide solution is added so only a single pass through the extruder is required. For Ex 19-25, the oil is injected into the extruder at pressures
15 in excess of the barrel pressure during a second pass of the compound through the extruder. The amounts of oil are shown in Table V together with proportional feed ratios for components of the compounds. Those skilled in the art can readily modify this procedure in any of a number of ways. One modification, involving a single pass, injects a peroxide solution into the front part of an extruder and oil
20 into the extruder prior to the end of the extruder.

Weigh feeders proportionally feed polymer components into the throat of the same extruder as used in Ex 18. Extrudate is pelletized as in Comp Ex J-K. For Ex 19-24 the peroxide amount is 6000 ppm. For Ex 25, the peroxide amount is 10,000 ppm. Ex 25 also includes 10 pbw of calcium
25 carbonate (CaCO_3).

For Ex 19-25, the extruder is operated under the same conditions as in Ex 18 to prepare an intermediate. This intermediate is then sent through the extruder at a flat temperature profile of 150°C for a second pass to add process oil and filler. For Comp Ex M and N (no peroxide modifier), a single
30 pass through the extruder allows addition of the process oil and filler. For Comp

Ex M and N, a single temperature of, respectively, 150°C and 175°C is used for all extruder zones.

The resulting compounds are injection molded into test plaques using an Arburg Model 370C-800-225 (800 kN hydraulic clamping force)

5 reciprocating screw injection molding machine (30 mm screw).

Injection molding processability is quantified by producing a plaque having an area of 154.8 square centimeters (cm²) and a thickness of 0.312 cm. The plaque is produced using an apparatus with barrel temperatures set in a profiled fashion with a first barrel zone at 107°C, subsequent zones sequentially at 107°C, 177°C, 196°C and 204°C, and a nozzle set at 196°C. A plaque mold temperature, while set at 18°C, is typically about 21°C during molding. The screw angular velocity and back pressure are, respectively, 30 mm/sec. and 10 bar (1 megapascal (MPa)). A shot volume of 65 cc is targeted for each plaque. The shot size and screw position at which the process switches from injection to hold is adjusted at the highest injection velocity to be evaluated such that the cavity is barely full. The time to fill the cavity to this point and the peak injection pressure are recorded at several injection velocities (5, 8, 10, 15, 20, 30, 50 and 70 cc/second). The peak injection pressure is plotted against the apparent shear rate (see Table VB) in the runner which is calculated using the injection velocity and mold physical dimensions. The peak injection pressure which results from the set injection velocity is used as an indication of processability since it is a process response dependent upon melt viscosity, injection velocity and the rate of solidification of the flow front.

Those skilled in the art of injection molding recognize that injection pressures are countered by clamp tonnage in a molding machine. They also recognize that unsuccessful injection molding resins will generate an injection pressure that exceeds available clamp tonnage prior to the mold cavity being filled at the highest practical melt temperature. When the peak pressure exceeds the clamp tonnage, flash occurs. As such, a compound that generates a significantly lower injection pressure at a given injection velocity (shear rate) than another resin is considered more processable.

The resulting compounds are subjected to physical property testing to determine Hardness (Shore A), I_2 , I_{10} , scratch/mar resistance, 80°C heat aging, and shear thinning behavior.

Hardness is determined in accordance with ASTM D 2249-91.

- 5 An average of 5 measurements is taken at intervals of 10 seconds on a 0.25 inch (0.6 cm) thick injection molded plaque.

- The 120°C Oven test involves placing an injection molded plaque (8 inch x 4 inch x 0.125 inch (20.3 cm x 10.2 cm x 0.3 cm) on a sheet of polytetrafluoroethylene (PTFE) in an oven set at a temperature of 120°C for a
10 period of 4 hours. The plaques are then visually evaluated by attempting to remove them from the PTFE sheet and rating samples as "good" if they can be removed without part distortion or destruction and "bad" if they are gooey and must be removed from the PTFE sheet by scraping with attendant part distortion.

- Scratch/mar resistance (SMR) is determined by swiping the
15 surface of an injection molded plaque with a saber saw blade in an "X" pattern. The plaques are then subjectively evaluated with those having the deepest grooves being rated as "bad" or "worse" and those with comparatively shallow grooves being rated as "good".

- Specific Gravity (SG) is determined in accord with ASTM D
20 792-86. I_2 and I_{10} are determined as explained above..

- Test results are shown in Table VI A-B. For purposes of comparison, the same tests are performed using a styrene/butadiene/styrene (SBS) polymer composition that is available from J-Von Limited Partnership under the trade designation Hercuprene™ 310D11. The SBS compound is designated as
25 Comp Ex O.

- The polymer components are as follows: EAO-4; EAO-11, an EO copolymer (Engage® 8400, DuPont Dow Elastomers L.L.C.) having an I_2 of 30 g/10 min and a ρ of 0.870 g/cc; EAO-12, an EO copolymer (Engage® 8402, DuPont Dow Elastomers L.L.C.) having an I_2 of 30 g/10 min and a ρ of 0.902
30 g/cc; PP-2; PP-4; EAO-6; and EAO-13, a linear EB copolymer (Exact® 5008, Exxon Chemical) that has an I_2 of 10 g/10 min and a ρ of 0.865 g/cc.

The oils are as follows: O-1, a naphthenic oil having a viscosity of 400 SUS at 100°F and being available from Shell Chemical as Shellflex® 371; O-2; and O-3.

Table V - Compounds

EAO-12	18	10	10	--	--	--	--	--	--
EAO-6	--	--	--	--	--	44	--	--	--
EAO-13	--	--	--	--	--	--	48	--	--
PP-4	--	15	15	19	12	11	12	9.3	12
O-1	40	--	--	--	--	--	--	--	--
O-2	--	--	--	--	40	45	40	39	40
O-3	--	40	40	40	--	--	--	--	--
Peroxide	N	N	Y	Y	Y	Y	Y	Y	Y

5 -- means not added; N means not added; Y means added

Table VIA - Test Results

Property /Test	Ex/Comp Ex.									
	M	N	O	19	20	21	22	23	24	25
Hardness (Shore A)	40	60	48	55	46	40	48.4	37.4	43	45
SG	0.89	n/a	1.05	n/a	n/a	0.87	0.87	0.87	0.93	0.87
I ₂ (g/10 min)	74	--	12	33	32	51	12	22	57	22
I ₁₀ (g/10 min)	1097	--	--	520	590	600	250	430	720	--
SMR	bad	bad	good	good	good	good	good	good	good	good
Oven Aging	Melts	1*	2*	3*	3*	3*	3*	3*	3*	3*
UST (°C)	55	64	81	88	--	--	--	--	--	105

Table VIB - Pressure (P) Test

Ex/ Comp Ex	M	N	O	19	20	21	22	23	24	25
Temp (°F/°C) for P Test	310/1 54	365/1 85	365/1 85	365/1 85	365/1 85	365/1 85	365/1 85	365/1 85	365/1 85	365/1 85
P (psi/ MPa) @ 22289 s ⁻¹	9000/ 62.0	5515/ 38.0	7718/ 53.2	5860/ 40.4	5299/ 36.5	5947/ 41.0	7416/ 51.1	7416/ 51.1	6494/ 44.8	7229/ 49.8
P (psi/ MPa) @ 15921 s ⁻¹	7417/ 51.1	4522/ 31.2	6408/ 44.2	4320/ 29.8	3845/ 26.5	4478/ 30.9	5890/ 40.6	5270/ 36.3	4882/ 33.7	5515/ 38.0
P (psi/ MPa) @ 9552 s ⁻¹	5936/ 40.9	3715/ 25.6	5342/ 36.8	3096/ 21.3	2693/ 18.6	3355/ 23.1	4468/ 30.8	3902/ 26.9	3614/ 24.9	4075/ 28.1
P (psi/ MPa) @ 6368 s ⁻¹	5118/ 35.3	3024/ 20.8	4882/ 33.7	2549/ 17.6	2275/ 15.7	2880/ 19.9	3787/ 26.1	3341/ 23.0	3024/ 20.8	3456/ 23.8
P (psi/ MPa) @ 4776 s ⁻¹	4667/ 32.2	2678/ 18.5	4680/ 32.3	2290/ 15.8	2059/ 14.2	2549/ 17.6	3485/ 24.0	3096/ 21.3	2794/ 19.3	3125/ 21.5
P (psi/ MPa) @ 3184 s ⁻¹	3976/ 27.4	2405/ 16.6	4594/ 31.7	2074/ 14.3	1872/ 12.9	2333/ 16.1	3139/ 21.6	2837/ 19.6	2549/ 17.6	2880/ 19.8
P (psi/ MPa) @ 2547 s ⁻¹	3722/ 25.7	2304/ 15.9	4579/ 31.6	1987/ 13.7	1829/ 12.6	2304/ 15.9	3038/ 20.9	2635/ 18.2	2419/ 16.7	2765/ 19.1
P (psi/ MPa) @ 1592 s ⁻¹	3800/ 26.2	2146/ 14.8	4694/ 32.4	1872/ 12.9	1771/ 12.2	2174/ 15.0	2923/ 20.2	2534/ 17.5	2246/ 15.5	2577/ 17.8

- 5 The data presented in Tables VIA and VIB demonstrate that compound viscosity is critical when a relatively thin walled (2-4 mm) long flow length (18 inches or 45.7 cm) part is injection molded. In Comp Ex M, the EAO compound fills a 4 mm thick, 45.7 cm long shaft of a work boot. In order to minimize polymer bleeding during injection of a boot sole, the EAO compound is
- 10 processed at a minimum temperature of 310°F (154°C) to achieve requisite fill and minimize polymer ST. When the compound of Comp Ex M is injected into a 2.5 mm thick, 45.7 cm long work boot shaft mold at 310°F (154°C), the

compound viscosity is so high that the mold is not completely filled. Increasing the temperature above 310°F (154°C) lengthens the polymer ST so that, during injection of the sole compound, polymer bleeding occurs. It is only when the UST and STI of an EAO-containing compound is improved, as demonstrated by the

5 oven aging and in-mold pressure data for Ex 19-25 in Tables VIA and VIB, that the compound properly fills the 2.5 mm thick, 45.7 cm long work boot shaft mold and generally precludes bleeding when the boot sole is injected on top of a portion of the shaft.

Ex 26

10 Using the procedure and the peroxide of Ex 1-3, a rheology-modified intermediate compound is prepared from 75 pbw of EAO-3, 20 pbw of PP-4 and 5 pbw of high density polyethylene (HDPE) (Dowlex® IP-60, The Dow Chemical Company). The peroxide, dispersed in O-2, is added at 10,000 ppm.

The intermediate compound, in an amount of 44 pbw, is

15 blended with 9 pbw of EAO-14, an EPDM terpolymer (Nordel® 4770, DuPont Dow Elastomers L.L.C.) having a Mooney viscosity of 70, an additional 7 pbw of HDPE, 7 pbw of CaCO₃ and 33 pbw of O-2 to obtain a final blend. Physical property test results, as with Ex 19-25 are summarized in Tables VIIA and VIB.

Ex 27

20 Using the procedure and peroxide of Ex 15, a rheology-modified intermediate is prepared from 45 pbw of EAO-8, 30 pbw of EAO-3 and 25 pbw of PP-4. The peroxide is added at a level of 5000 ppm.

Table VIIA

Property/ Test	Ex/Comp Ex	
	26	27
Hardness (Shore A)	55	51
SG	0.93	0.88
I ₂ (g/10 min)	11	12
I ₁₀ (g/10 min)	200	400
SMR	Good	good
Oven Aging	Good	good
UST (°C)	112	94

Table VIIB - Pressure (P) Test

5

Ex/ Comp Ex	26	27
Temp (°F/°C) for P Test	365/1 85	365/1 85
P (psi/ MPa) @ 22289 s ⁻¹	8136/ 56.1	7500/ 51.7
P (psi/ MPa) @ 15920 s ⁻¹	6480/ 44.7	5800/ 40.0
P (psi/ MPa) @ 9552 s ⁻¹	5213/ 35.9	4400/ 30.3
P (psi/ MPa) @ 6368 s ⁻¹	4579/ 31.6	3800/ 26.2
P (psi/ MPa) @ 4776 s ⁻¹	4291/ 29.6	3450/ 23.8

Table VIIB (Contd.)		
P (psi/ MPa) @ 3184 s ⁻¹	3989/ 27.5	3200/ 22.1
P (psi/ MPa) @ 2547 s ⁻¹	3917/ 27.0	3050/ 21.0
P (psi/ MPa) @ 1592 s ⁻¹	3773/ 26.0	2950/ 20.3

The data presented in Tables VIIA and VIIB demonstrate two key points. First, Ex 26 shows that a rheology-modified compound representative of the present invention can be blended with an EAO that is not rheology-modified to provide a final blend with satisfactory properties. Second, Ex 27 shows that a rheology-modified blend of two EAO polymers and a PP polymer can be extended with additional processing oil and still provide satisfactory physical properties.

Ex 28-29 and Comp Ex P-Q

Four sample materials are prepared using EAO-4 as the EAO.

10 In Comp Ex P, EAO-4 is processed through an injection molding apparatus as detailed below without a blowing agent. In Comp Ex Q, a blowing agent (EPIcor™ 882, a proprietary endothermic concentrate commercially available from EPI Environmental Products) is added to EAO-4 in an amount of 2 wt%, based on polymer weight. In Ex 28, a blend of 80 % EAO-4 and 20% of PP-2, 15 both percentages being based on combined weight of polymers, is modified as in Ex 8 with 6000 ppm of peroxide. In Ex 29, the composition of Ex 28 is modified with 2% by weight of the same blowing agent as in Comp Ex Q.

All compositions are processed using an Arburg 370C injection molding apparatus that has a screw operating at a tip speed of 30 mm per second, 20 a back pressure set at 10 bar (1 MPa), a dosage set at 40 cc, and the following zones and associated temperatures: feed zone = 400°F (204°C), Zone 2, 420°F (216°C), Zones 3 and 4 440°F (227°C), nozzle = 430°F (221°C) to provide a melt temperature of 455°F (235°C) as measured by infrared pyrometry. Extrudate from

the apparatus is injected at a velocity of one cubic centimeter per second (cc/sec) over a fill time of 1.28 sec into a 1" x 6" x 0.225" (2.5 cm x 15.2 cm x 0.3 cm) mold that is at a temperature of 90°F (32°C) to provide a molded bar. The mold is held at a pressure of 700 bar (70 MPa) for 30 seconds, then cooled for an
5 additional 45 sec before removal of the molded bar.

A visual inspection of the molded bars shows that neither Comp Ex P nor Comp Ex Q provides a desirable bar. Comp Ex P is dimensionally unstable, with dimensions that differ from those of the mold, and aesthetically unacceptable. Comp Ex Q is foamed and has the same dimensions as
10 the mold, but with a poor surface due to gas entrapment that leads to, among other undesirable features, pitting. By contrast, Ex 29 yields a bar with a much better surface than Comp Ex Q, a higher part mass than either Comp Ex P or Comp Ex Q, and several more and finer bubbles than the bar of Comp Ex Q. Similar results are expected with Ex 28 and other compositions of the present invention.

15 Ex 30-31

An amount of a peroxide imbibed onto a solid carrier (LupercosTM 802-40KE, commercially available from Elf Atochem, North America) that is sufficient to provide an active peroxide level of 6000 ppm is dry
20 blended with an amount of PP-3 and an amount of EAO-4 and then processed to provide a melt at a temperature of 375°F (191°C) using a 44:1 length to diameter (L/D) ratio, single screw extruder operating at a screw speed of 25 rpm. Ex 30 has 10% PP-3 and 90% EAO-4 and Ex 31 has 20% PP-3 and 80% EAO-4. Extrudate is pelletized at a rate of 220 pounds per hour (pph) for Ex 30 and 186 pph for Ex 31. The pellets yield a product via extrusion or injection molding that is
25 substantially gel-free. The STI for Ex 31 is 100

Ex 30 and 31 demonstrate that compositions of this invention may be processed on a single screw extruder. Similar results are expected with other compositions of this invention.

Ex 32-36 and Comp Ex R

Six compositions containing 64.6% EAO-1, 29.6% of PP-5, a P/E copolymer (Profax® 8623 with a MFR of 2 g/10 min commercially available from Himont), varying levels of peroxide and 4.8% CaCO₃ (Omyacarb™ UF available from Omya, Inc) are processed using two apparatus in series. They are first processed using a twin screw extruder as in Ex 1-3. They are then processed on a calendering apparatus. The calendering apparatus is fed by an extruder that has the following temperature profile: feed zone, 290°F (143.3°C); zone 2, 300°F (148.9°C), zone 3, 350°F (176.7°C) and die temperature, 365°F (185°C). The apparatus has a bottom roll, a center roll and a top roll. The top roll is neutral in that it applies no pressure. The bottom roll temperature is 307°F (152.8°C) and the center roll temperature is 130°F (54°C). The melt temperature at the calendar feed is 365°F (185°C). The bottom roll has a speed of 0.1 yard/min (0.09 meter/min) and the center roll has a speed of 3.8 yard/min (3.47 meters/min). The apparatus produces a film having a thickness of 20 mils (0.5 mm). Five of the compositions (Ex 32-36) have peroxide levels as shown in Table VIII. The sixth composition (Comp Ex R) contains no peroxide.

The calendered compositions are subjected to physical property testing as in Ex 1-3. Test results are also shown in Table VIII.

Table VIII

Ex/Comp Ex.	Peroxide Level,	UST (°C)	MS (cN)
R	0	62	--
32	3500	77	9.5
33	4500	81	--
34	5500	85	10.8
35	6500	86	14
36	7500	94	16

-- means not measured

5 The results in Table VIII show that rheology modification provides satisfactory results when compositions are subjected to calendering. These results suggest satisfactory performance in calendering applications such as roofing membranes and automotive trim.

10 Results similar to those shown in Examples 1-36 are expected with other polypropylene resins, EAO polymers and EAO polymer blends, other rheology modifiers or processes and other additives such as fillers and process oils, all of which are disclosed herein.

WHAT IS CLAIMED IS:

1. A rheology-modified, substantially gel-free TPE composition comprising at least one elastomeric EAO polymer or EAO polymer blend and at least one high melting polymer selected from polypropylene homopolymers and propylene/ethylene copolymers, the composition having at least three of four characteristics, the characteristics being a STI ≥ 20 , a MS ≥ 1.5 times that of the composition without rheology modification, a ST $\geq 10^\circ \text{C}$ greater than that of the composition without rheology modification, and an UST limit $\geq 10^\circ \text{C}$ greater than that of the composition without rheology modification.
2. The composition of Claim 1, wherein the rheology modification is peroxide induced using a level of peroxide sufficient to provide the combination of characteristics, the peroxide being an organic peroxide selected from α , α' -bis(t-butylperoxy)-diisopropylbenzene, dicumyl peroxide, 2,5-dimethyl-2,5-di(t-butylperoxy)hexyne-3, 2,5-dimethyl-2,5-di(t-butylperoxy)hexane, 2,5 (t-amyl peroxy-2-ethylhexonate), 2,5-dimethyl-2,5-di-(t-butyl peroxy)hexane, di-t-butylperoxide, 2,5-di(t-amyl peroxy)-2,5-dimethylhexane, 2,5-di-(t-butylperoxy)-2,5-diphenylhexane, bis(alpha-methylbenzyl)peroxide, t-butyl perbenzoate, benzoyl peroxide and bis(t-butylperoxy)-diisopropylbenzene.
3. The composition of Claim 1, wherein the EAO polymer has polymerized therein at least one C_{3-20} α -olefin comonomer.
4. The composition of Claim 1, wherein the EAO polymer is a diene-modified polymer, the diene being selected from norbornadiene, dicyclopentadiene, 1,4-hexadiene, piperylene or 5-ethylidene-2-norbornene and mixtures thereof.
5. The composition of Claim 1, further comprising at least one additive selected from process oils, fillers and blowing agents, the process oil

being present in an amount within a range of 0-50 weight percent, the filler being present in an amount within a range of 0-70 weight percent, and the blowing agent being present in an amount within a range of 0-10 weight percent, all amounts being based on total composition weight, the filler, when present, being selected
5 from glass, silica, carbon black, metal carbonates, metal sulfates, talc, clay and graphite fibers.

6. The composition of Claim 1, further comprising an amount of an EAO polymer that is substantially free of rheology modification.

7. A process for preparing the composition of any of
10 Claims 1-6, the process comprising: a) providing a combination of an organic peroxide and a molten polymer composition that comprises at least one of (1) an elastomeric EAO polymer or EAO polymer blend and (2) a high melting polymer selected from polypropylene homopolymers and propylene/ethylene copolymers; b) maintaining the combination in a melt state while subjecting it to conditions of
15 shear sufficient to disperse the peroxide throughout the molten polymer composition, effect sufficient rheology modification of the molten polymer composition and substantially preclude formation of insoluble polymer gels, sufficient rheology modification being attainment of at least three of four characteristics, the characteristics being a $STI \geq 20$, a $MS \geq 1.5$ times that of the
20 polymer blend without rheology modification, a $ST \geq 10^\circ C$ greater than that of the polymer blend without rheology modification, and an UST limit $\geq 10^\circ C$ greater than that of the polymer blend without rheology modification; and, optionally, c) converting the rheology-modified molten polymer composition into an article of manufacture that has the combination of at least three of four
25 characteristics.

8. The process of Claim 7, further comprising sequential intermediate steps b1) and b2) that precede step c), step b1) comprising recovery of the rheology modified polymer blend as a solid and step b2) comprising

conversion of the solid to a melt state sufficient for fabricating the article of manufacture.

9. The process of Claim 7 or Claim 8, wherein the combination is prepared by one of (a) forming the molten polymer composition
5 and then adding the organic peroxide to the molten polymer composition, or (b) adding the organic peroxide to at least one component of the polymer composition and then converting the composition to a molten polymer composition.

10. The process of Claim 7 or Claim 8, wherein the high melting polymer is added to the molten polymer composition while the
10 composition is in a melt state, but subsequent to rheology modification of the elastomeric EAO polymer or elastomeric EAO polymer blend.

11. An article of manufacture having at least one component thereof fabricated from the composition of any of Claims 1-6, the article of manufacture being selected from a) as automobile body parts, bumper
15 fascia, body side moldings, exterior trim, interior trim, air dams, air ducts, wheel covers and instrument and door panel skins, b) as non-automotive applications, polymer films, polymer sheets, swim fins, trash cans, storage containers, lawn furniture strips or webbing, lawn mower and other garden appliance parts, recreational vehicle parts, golf cart parts, utility cart parts and water craft parts,
20 roofing applications including roofing membranes, and c) footwear components including shafts for a boot.

12. The article of manufacture of Claim 11 as prepared by the process of any of Claims 7-10.

INTERNATIONAL SEARCH REPORT

International Application No.

PCT/US 98/01625

A. CLASSIFICATION OF SUBJECT MATTER
 IPC 6 C08L23/16 C08L23/10

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 C08L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 375 531 A (ROSS JAMES F) 1 March 1983 see column 1, line 1 - line 14 see column 3, line 40 - line 55; claims ---	1-10
X	US 4 535 125 A (MCCULLOUGH JR J DOUGLAS) 13 August 1985 see column 2, line 5 - line 38 see column 4, line 15 - column 5, line 25; claims ---	1-12
A	GB 1 192 189 A (CHEMISCHE WERKE HÜLS AKTIENGESELLSCHAFT) 20 May 1970 see page 1, line 9 - line 19 see page 3, line 32 - line 36; claim 1 -----	1-12

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

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